Effects of Plant Growth Regulators Applied as Sprays or Media Drenches on Forcing of Dutch-grown Bleeding Heart as a Flowering Potted Plant

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ADDITIONAL INDEX WORDS. ancymidol, chlormequat, daminozide, *Dicentra spectabilis*, flowering potted plants, foliar sprays, Fumariaceae, media drenches, paclobutrazol, uniconazole

SUMMARY. Two experiments were conducted to determine the effects of applied ancymidol, chlormequat, daminozide, paclobutrazol, and uniconazole on early spring (March) and late (May) spring forcing of Dutch-grown Bleeding Heart [*Dicentra spectabilis* (L.) Lem.] as a flowering pot plant. Most of the plant growth regulator (PGR) treatments delayed flowering, however, the average time to flower after planting was from 17 to 21 days for untreated plants and delays were only 3 to 6 days with PGR treatments. Thus, the effect is not important commercially. Acceptable plant quality and height

control not only at flowering but also 14 days later was obtained with two sprays of 3000 mg·L⁻¹ (ppm) daminozide or two sprays of 50 mg·L⁻¹ paclobutrazol. Uniconazole reduced total plant height, however, because the inflorescence did not elongate, plant quality was greatly reduced. Most ancymidol sprays were phytotoxic producing a chlorosis of the leaf margins. Media drenches of ancymidol or chlormequat did not control total plant height. Sprays and media drenches of ancymidol, daminozide, paclobutrazol, and uniconazole produced plants with a very deep green leaf color, but chlormequat did not. The total number of shoots per tuberous root, the number of shoots with flowers, and stem strength were not significantly affected by PGR treatments. If the tuberous roots have been properly cold treated, they initiate growth rapidly after planting. Thus, the first PGR spray must be applied immediately after shoot growth is initiated, which was 6 to 8 days after planting, followed by a second spray 5 days later. Two applications are necessary because of uneven shoot emergence and growth from the tuberous roots.

edly and species are grown from seed, cuttings or forced storage organs (Armitage 1997). The Bleeding Heart (*Dicentra spectabilis*) is a readily available tuberous rooted perennial, but flowering plants are tall [45 to 90 cm (18 to 36 inches)] (Armitage, 1997). The plants are excellent for shaded gardens and have long inflorescences with attractive heart-shaped flowers. The physiology of flowering of *D. spectabilis* has been reviewed by Weiler and Lopes (1985). Lopes and Weiler (1977b), Roberts et al. (1995), and Weiler and Kirk (1984) demonstrated that ancymidol and daminozide effectively reduced total plant height of *D. spectabilis* by up to 58%. However, Smith (1992), Weiler (1984), and Weiler and Kirk (1984) advised that only daminozide should be used for commercial forcing of *D. spectabilis* as a potted plant. Roberts et al. (1995) have demonstrated that a flowering potted plant has an indoor life of about 10 d. Because only a limited number of PGRs have been studied, the objectives of our trials were 1) to evaluate the readily available PGRs (Tayama et

In the past 2 decades, the use of perennials in North American gardens has increased mark-

Fig. 1. Stage of shoot development of Bleeding Heart (*Dicentra spectabilis*) to spray with plant growth regulator for optimal plant height control.

We thank the Jac. Th. de Vroomen Bulb Company, Lisse, The Netherlands, for packing, shipping and donating the tuberous roots. We also acknowledge the technical assistance of Lena Gallitano and Nancy Mingis for her assistance with the statistical analyses. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service or criticism of similar ones not mentioned. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* to indicate this fact.

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Table 1. Days to flower, total plant height at flowering and 14 d later, height of inflorescence at flowering, total number of inflorescences and ratings of stem strength, phytotoxicity, and leaf color of Bleeding Heart (*Dicentra spectabilis*) treated with plant growth retardants (PGR) in Expt. 1 (early spring forcing).

PGR ^z	Application method and rate ^y (media drench, a.i./pot) (foliar spray)	Days to flower	Total plant ht (cm) ^x		Inflorescence ht (cm)		Stem strength	Rating ^v	
			At flowering	Plus 14 d	at flowering ^{xw}	Inflorescence ^w (no.)		Phyto- toxicity	Leaf color
None		20.9	46.72	60.7	45.0	7.5	2.5	1.0	2.9
Ancy	Media drench, 0.5 mg (0.014 oz)	21.5	45.1	59.6	43.2	7.8	2.3	1.1	3.0
Ancy	Media drench, 1.0 mg (0.028 oz)	22.0	40.9	55.0	38.9	9.1	2.6	1.0	3.6
Ancy	Foliar spray, 50 mg·L ⁻¹ (ppm)	23.1	44.5	59.6	42.7	7.7	2.9	2.0	3.6
Ancy	Foliar spray, 100 mg·L ⁻¹ (ppm)	26.6	34.3	46.2	31.4	5.4	2.8	3.6	3.9
Chlor	Foliar spray, 1000 mg·L ⁻¹ (ppm)	20.5	45.4	58.1	44.1	8.4	2.6	1.0	3.0
Chlor	Foliar spray, 2000 mg·L ⁻¹ (ppm)	20.1	44.9	59.6	43.9	9.2	2.6	1.0	3.0
Damin	Foliar spray, 1500 mg·L ⁻¹ (ppm)	22.8	36.9	50.1	34.7	8.5	2.5	1.2	3.2
Damin	Foliar spray, 3000 mg·L ⁻¹ (ppm)	24.8	26.2	36.5	24.5	6.3	2.4	1.0	3.7
Paclo	Media drench, 1.0 mg (0.028 oz)	23.1	47.0	55.9	45.0	6.7	2.3	1.0	3.0
Paclo	Media drench, 2.0 mg (0.056 oz)	20.2	46.2	59.7	44.6	8.3	2.5	1.0	3.0
Paclo	Foliar spray, 50 mg·L ⁻¹ (ppm)	23.5	28.5	43.3	27.2	8.3	3.0	1.1	4.6
Paclo	Foliar spray, 100 mg·L ⁻¹ (ppm)	26.3	17.6	26.8	15.4	7.2	2.8	1.0	5.0
Unic	Media drench, 0.1 mg (0.0028 oz)	22.6	49.4	64.4	47.8	8.7	2.6	1.0	3.0
Unic	Media drench, 0.2 mg (0.0056 oz)	20.3	45.7	58.1	44.6	10.8	2.7	1.0	3.0
Unic	Foliar spray, 5 mg·L ⁻¹ (ppm)	24.9	37.1	55.0	34.8	7.9	2.6	1.0	4.0
Unic	Foliar spray, 10 mg·L ⁻¹ (ppm)	25.4	19.5	38.3	17.1	7.2	2.9	1.1	5.0
Unic	Foliar spray, 20 mg·L ⁻¹ (ppm)	24.6	19.0	28.5	17.0	6.2	3.0	1.0	5.0
LSD _{0.05}		2.2	5.6	5.9	5.4	2.0	0.5	0.2	0.4
LSD _{0.05}		2.9	7.4	7.9	7.2	2.7	0.6	0.3	0.5

^zAncy = ancymidol, Chlor = chlormequat, Damin = daminozide, Paclo = paclobutrazol, Unic = uniconazole.

^yApplication methods: Media drench, mg (oz) a.i./pot, 1 mg = 0.028 oz; foliar spray, mg·L⁻¹ (ppm). All media drenches were applied once and foliar sprays twice, 5 d apart.

^x2.5 cm = 1.0 inches.

^wOnly flowering date data are presented.

^vStem strength and phytotoxicity (1 = poor and 4 = excellent); leaf color (1 = pale green and 5 = dark green).

al., 1992) and 2) to compare PGR application methods on the growth, development, and flowering of *D. spectabilis* as a flowering potted plant. Special emphasis was placed not only controlling total plant height at flowering (marketable stage) but also on reducing growth two weeks after reaching the flowering stage. Experiment 2 was designed after the completion of Expt. 1 and only the effective PGRs and application methods were used.

Materials and methods

GENERAL ASPECTS. Tuberous roots were grown in the Netherlands and harvested in early December 1997. Postharvest storage was at 0 to 2 °C (32 to 35 °F) and 100% relative humidity. After being graded, No. 1 tuberous roots were packed in perforated polyethylene bags, placed in perforated cardboard boxes, and shipped by container at 2 °C (35 °F) to the United States on 18 Dec. 1997. They arrived in Russell, Ill. on 31 Dec. 1997, were shipped by United Parcel Service on 6 Jan. 1998, and arrived in Raleigh, N.C., on 8 Jan. 1998. After arrival, the

tuberous roots were kept in the shipping boxes and stored at 2 °C until planted.

One tuberous root was planted per 6-inch (15-cm) diameter standard plastic pot [1.8 L (0.5 gal)]. When necessary, roots were pruned to facilitate planting the crown just above the pot rim (Weiler and Kirk, 1984). Sunshine Mix No. 4 (Fisons Horticulture Inc., Bellevue, Wash.), a 60/40 mixture of coarse peat and perlite, pH 6.3, was used as the planting medium. After a thorough initial watering, the medium was kept moist until the plants began to grow rapidly. Then, the medium was watered daily. Plants were fertilized with 6 g (0.2 oz) of 14-14-14 (14N-6.2P-11.6K) Osmocote (Scotts Co., Marysville, Ohio) per pot which was broadcast on the medium surface when shoot growth was observed (Fig. 1). Pots were placed in a double layer polyethylene covered greenhouse and were forced under naturally increasing photoperiods of 10 h 59 min (17 Feb.) to 13 h 55 min (10 May). Prevailing light intensities were reduced by 50% by placing a

mesh netting over the entire greenhouse for the duration of the forcing period and greenhouse set points were at 17 °C (63 °F) nights for heating and 27 °C (80 °F) days for cooling (Lopes and Weiler, 1977a; Weiler and Lopes, 1976). Microscopic observations of shoot samples on the two planting dates indicated that they were reproductive.

The PGRs used were ancymidol (A-Rest), chlormequat (Cycocel), daminozide (B-Nine-SP), paclobutrazol (Bonzi), and uniconazole (Sumagic).

A randomized complete block design with four blocks and five observations (pots) per plot was used. Data were recorded twice for each plant; initially, when it reached full (market) flower (three fully colored florets per inflorescence) and, again, 2 weeks after reaching the full flower stage. Total plant height was measured from the pot rim to the uppermost part of the vegetative canopy. Inflorescence height was measured from the pot rim to the top of the uppermost inflorescence. Total number of shoots included all

Table 2. Days to flower, total plant height at flowering and 14 d later, height of inflorescence at flowering, total number of inflorescences and ratings of plant quality at flowering and 14 d later, and leaf color of Bleeding Heart (*Dicentra spectabilis*) treated with plant growth retardants (PGR) in Expt. 2 (late spring forcing).

PGR ^z	Application method and rate ^y (media drench, a.i./pot) (foliar spray)	Days to flower	Total plant ht (cm) ^x		Inflorescence ht (cm) at flowering ^{xy}	Inflorescence ^w (no.)	Plant quality ^v		Leaf color
			At flowering	Plus 14 d			At flowering	Plus 14 d	
None		17.5	44.9	57.8	42.6	8.7	1.8	1.4	1.0
Damin	Foliar spray, 3000 mg·L ⁻¹ (ppm)	20.2	28.0	39.0	27.1	9.1	2.3	3.2	2.3
Paclo	Media drench, 2 mg (0.056 oz)	19.7	18.2	28.0	15.5	8.6	1.6	2.1	2.9
Paclo	Media drench, 2 mg (0.056 oz) + Foliar spray, 50 mg·L ⁻¹ (ppm)	20.0	14.8	21.1	13.7	9.2	1.2	1.8	3.5
Paclo	Foliar spray, 50 mg·L ⁻¹ (ppm)	20.3	25.1	44.6	23.1	8.6	2.2	2.5	2.2
Paclo	Media drench, 2 mg (0.056 oz) + Foliar spray, 100 mg·L ⁻¹ (ppm)	21.0	12.8	16.9	11.1	7.2	1.2	1.3	3.9
Paclo	Foliar spray, 100 mg·L ⁻¹ (ppm)	20.3	17.0	26.7	15.2	7.0	1.6	1.7	3.1
Unic	Media drench, 0.2 mg (0.0056 oz)	17.5	41.1	58.2	39.1	10.8	1.6	1.4	2.0
Unic	Media drench, 0.2 mg (0.0056 oz) + Foliar spray, 1 mg·L ⁻¹ (ppm)	20.3	27.0	43.9	25.3	8.2	1.8	1.5	2.9
Unic	Foliar spray, 1 mg·L ⁻¹ (ppm)	20.3	39.8	56.3	37.7	9.8	2.0	1.6	1.8
Unic	Media drench, 0.2 mg (0.0056 oz) + Foliar spray, 5 mg·L ⁻¹ (ppm)	20.8	17.9	30.2	16.7	8.5	1.5	1.4	3.1
Unic	Foliar spray, 5 mg·L ⁻¹ (ppm)	20.5	16.8	33.4	15.0	8.5	2.0	1.8	3.0
LSD _{0.05}		1.3	6.5	8.8	6.3	2.0		0.4	0.4
LSD _{0.05}		1.7	8.7	11.9	8.5	2.7		0.6	0.5

^zDamin = daminozide, Paclo = paclobutrazol, Unic = uniconazole.

^yMedia drench, mg (oz) a.i./pot, 1 mg = 0.028 oz; foliar spray, mg·L⁻¹ (ppm). All media drenches were applied once and foliar sprays twice, 5 d apart.

^x2.5 cm = 1.0 inches.

^wOnly flowering date data are presented.

^vPlant quality (1 = poor and 4 = excellent); leaf color (1 = pale green and 5 = dark green).

that developed from the crown, while flowering shoots were only those with an inflorescence. For the subjective observations of stem strength, plant quality and phytotoxicity, a rating of 1 = poor to 4 = excellent was used. Stem strength was determined by the ability of the stems and inflorescences to withstand plant handling and movement. Plant quality was based on total plant height, length of the inflorescence, inflorescence number, stem strength, leaf color and phytotoxicity symptoms. Phytotoxicity was based on the presence and/or degree of foliar chlorosis. Foliage color was rated 1 = pale green to 5 = very dark green. Foliage color was rated from a pale green (1) to a very dark green (5). Mean comparisons among treatments was by LSD ($P \leq 0.05$).

EXPERIMENT 1 (EARLY SPRING FORCING). Planting date was 17 Feb. 1998 with 18 treatments Table 1 (Table 1). PGR media drenches were applied on 25 Feb. (8 d after planting) using 100 mL (3.4 fl oz) of solution per pot for ancymidol and paclobutrazol and 125 mL (4.2 fl oz) per pot for uniconazole. PGR sprays were applied on 25 Feb. (8 d after planting) and 2 Mar. (13 d after

planting) using ≈ 10 and 15 mL (3.7 and 0.51 fl oz) of solution per plant, respectively. The amount applied was determined by collecting an identical amount of spray in a graduated cylinder. The active amounts per plant for each PGR can be calculated from the rates provided in Tables 1 and 2.

EXPERIMENT 2 (LATE SPRING FORCING). Planting date was 15 Apr. 1998 with 12 treatments (Table 2). PGR media drenches were applied on 17 Apr. (2 d after planting) and sprays were applied on 21 Apr. (6 d after planting) and 26 Apr. (11 d after planting) as described in Expt. 1. Drenches were applied earlier than in Expt. 1 to maximize uptake by the roots.

Results

EXPERIMENT 1. No interactions occurred between the two data recording dates and PGR treatments, and plant quality was not affected by any treatment. Therefore, only data from the first date are presented in Table 1 for the number of inflorescences, stem strength, leaf color, and phytotoxicity. Compared to nontreated plants (Table 1), flowering was significantly delayed by the 100 mg·L⁻¹ (ppm) ancymidol sprays, 3000

mg·L⁻¹ daminozide sprays, the 50 and 100 mg·L⁻¹ sprays of paclobutrazol, and all uniconazole sprays [5, 10, and 20 mg·L⁻¹]. Total plant and inflorescence heights were significantly reduced not only at flowering but also two weeks after flowering by the 100 mg·L⁻¹ ancymidol sprays, 1500 and 3000 mg·L⁻¹ daminozide sprays, the 50 and 100 mg·L⁻¹ sprays of paclobutrazol, and 10 and 20 mg·L⁻¹ uniconazole sprays. The 5 mg·L⁻¹ uniconazole sprays and 1.0 mg (0.028 oz) a.i. media drench of ancymidol significantly reduced plant height only on the date of flowering. The total number of shoots and flowering shoots were not significantly affected by the PGR treatments (data not shown). However, the total number of inflorescences was significantly decreased by the 100 mg·L⁻¹ ancymidol sprays and significantly increased by the 0.2 mg (0.0056 oz) a.i. per pot media drench of uniconazole. Stem strength relative to the controls was not significantly affected by any PGR treatment. Leaf phytotoxicity (chlorosis), was induced by the 50 and 100 mg·L⁻¹ ancymidol sprays. Deep green leaves were obtained with the 50 and 100

mg·L⁻¹ sprays and the 1.0 mg a.i. media drench of ancymidol, the 3000 mg·L⁻¹ daminozide sprays, the paclobutrazol sprays (50 and 100 mg·L⁻¹), and all uniconazole sprays (5, 10, and 20 mg·L⁻¹). No disease or insect problems were observed in this experiment. Two weeks after flowering, lower leaf yellowing occurred with most of the treatments, which appeared to be normal foliar senescence.

EXPERIMENT 2. Because ancymidol sprays were phytotoxic (Table 1) and the ancymidol media drenches and chlormequat sprays were ineffective, these PGRs were not included in Expt. 2 (Table 2). In addition, since long term plant height control was desired, media drenches and sprays were combined to determine if this system could be effective.

The only interaction between dates and PGR treatments occurred with plant quality (Table 2). The number of days to flower was significantly increased by all PGR treatments, except the 0.2 mg a.i. media drench of uniconazole. Total plant and inflorescence height were significantly reduced not only at flowering but also 2 weeks later by all the PGR treatments, except the 1 mg·L⁻¹ uniconazole sprays and the 0.2 mg a.i. media drench of uniconazole. These were the lowest rates used for these methods of PGR application. As in Expt. 1, there were no significant effects of the PGR treatments on the total number of shoots or flowering shoots (data not shown). In addition, stem strength was not affected (data not shown). Plant quality was significantly increased by the 3000 mg·L⁻¹ daminozide sprays (Fig. 2) and the paclobutrazol combination of 2.0 mg (0.056 oz) a.i. drench plus 50 mg·L⁻¹ sprays. All PGRs significantly increased the green leaf color. As with Expt. 1, lower leaf yellowing again occurred but mainly with the media drenches. No phytotoxicity symptoms were obtained with the PGR treatments and no disease or insect problems were observed.

Discussion

We propose that a highly marketable flowering potted plant of Bleeding Heart should have dark green foliage, and be 25 to 35 cm (10 to 14 inch) in height when the plant has three fully colored flowers. In addition, postflowering growth should be

10 cm (4 inches) or less. For many floricultural crops, PGRs are used to achieve these criteria (Tayama, 1992).

In both experiments (Tables 1 and 2), two sprays of 3000 mg·L⁻¹ (ppm) daminozide produced plants with acceptable height. These data confirm the reports of Lopes and Weiler (1977b) and Roberts et al. (1995) that foliar sprays of 2500 mg·L⁻¹ or higher of daminozide are effective for plant height control of forced *D. spectabilis*. Roberts et al. (1995) reported that a single 5000 mg·L⁻¹ daminozide spray had no effect on the time to flower. However, we obtained a 4-d delay in flowering with two spray applications of 3000 mg·L⁻¹. Lopes and Weiler (1977b) found a delay in flowering with 7500 to 15000 mg·L⁻¹ daminozide sprays, which are very high rates for this PGR. Similar, small but significant, delays in flowering have been reported for several cultivars of tuberous rooted dahlias (*Dahlia variabilis* Willd.) (Whipker et al., 1995; Whipker and Hammer, 1997). None of the investigators reported phytotoxicity with daminozide sprays even at very high rates. Thus, Bleeding Heart is very tolerant to this PGR, which is important for commercial forcers.

Weiler and Kirk (1984) reported that ancymidol sprays of 10 and 25 mg·L⁻¹ were not effective in reducing plant height of *D. spectabilis*, whereas, media drenches and preplant dips greatly reduced plant height. We found (Table 1) that two sprays of 50 and 100 mg·L⁻¹ ancymidol significantly reduced total plant height, but phyto-

toxic symptoms were evident. In contrast, De Hertogh et al. (1976), Whipker et al. (1995) and Whipker and Hammer (1997) found that ancymidol drenches were effective plant growth retardants for tuberous rooted dahlias and were not phytotoxic up to 4 mg (0.11 oz) a.i. per pot. However, Whipker and Hammer (1997) observed leaf distortion and phytotoxicity with 8 mg (0.22 oz) a.i. per pot, which is a very high rate for this PGR.

The effects of paclobutrazol and uniconazole on Bleeding Heart have not been reported. We found that spray applications of both PGRs effectively reduced total plant height without phytotoxicity (Tables 1 and 2) and that two spray applications of 50 mg·L⁻¹ paclobutrazol can be used. Plants were highly responsive to uniconazole and the effective rate appears to be between 1 to 5 mg·L⁻¹. Additional research is needed to identify optimal rates for these PGRs, because neither was phytotoxic.

Lopes and Weiler (1977b) reported that chlormequat was not effective on *D. spectabilis* either as a spray or media drench. Our data (Table 1) confirm that chlormequat sprays are ineffective. They also reported that ethephon did not reduce total plant height, but significantly delayed flow-

Fig. 2. Untreated (control) Bleeding Heart (*Dicentra spectabilis*) plant (left) and plant sprayed twice with 3000 mg·L⁻¹ (ppm) daminozide (right); photographed 15 d after planting in Expt. 2.

ering. Therefore, ethephon was not included in this study.

Even though plant height was significantly reduced (Tables 1 and 2), plant strength was not significantly affected by PGR treatments (Table 1). Presumably, this is because the stem tissue is soft and herbaceous. In addition, the total number of shoots and those with inflorescences were not significantly affected. We have assumed that these characteristics are under the control of other factors and were determined before the plants were treated. This response was also reported for tuberous rooted dahlias by De Hertogh et al. (1976).

Conclusions

Our goal was to 1) produce potted plants of Bleeding Heart that were 25 to 35 cm (10 to 14 inches) tall when flowering commenced and 2) to maintain plant height control for another 14 d. This was achieved with two spray applications of either 3000 mg·L⁻¹ (ppm) of daminozide or 50 mg·L⁻¹ of paclobutrazol. To effectively control plant quality and height, plants must be observed daily after planting. If tuberous roots have been properly cold treated, they initiate shoot growth rapidly after planting. Thus, PGR spray applications must be carried out immediately after shoot growth is visible (Fig. 1), which is generally 6 to 8 d after planting, and the second application is made 5 d later. Multiple sprays are necessary because of uneven shoot emergence and growth. If this is not carried out, the plants normally develop one or more very long inflorescences, while others are shorter. Thus, the flowering potted plant is not uniform in flowering. Consumers should be advised to keep the planting medium watered while plants are in the home. Subsequently, after they have flowered, the plants can be planted in a shady garden area to preserve them for the next flowering season.

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